NASA Kennedy Space Center
Electrostatics and Surface Physics Laboratory

Final Report: Electrostatic Evaluation of the SRB Velostat™ Pads

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1.0 Background

During RSRM Grain inspection, pads constructed of Velostat™ are grounded and installed in the RSRM bore enabling inspectors to move throughout the bore during the inspection. Velostat pads are installed by grounding the first pad installed and subsequent pads are installed overlapping the previously installed pad maintaining a conductive path to facility ground. Pads are removed upon completion of the inspection in a reverse fashion. As the pads are removed scanning of propellant surfaces is performed per OMRS.

During PPICI Audit of B5308.006 (Forward Segment Grain Inspection) in October 07 one audit finding noted that electrostatic scanning of propellant surfaces was being performed during removal of conductive pads following grain inspection. ATK does not perform electrostatic scanning of propellant surfaces during pad removal following final inspection at the plant. The integrated team consisting of NASA SE, USA SE, USA QE, ATK LSS, ATK Systems Safety and ATK DE concurred that electrostatic scanning of propellant surfaces was unnecessary as the conductive pads are grounded. Additional time spent in bore performing scanning presents itself as additional risk. Technicians reported that they have never seen any voltage readings while scanning propellant surfaces during pad removal. USA Systems engineering has written KB17530 in response to the finding which will delete the requirement (item 2 B47GEN.110) to scan propellant surfaces during pad removal.

As a result of an E3 panel discussion on December 13, 2007, it was decided that verification of the electrical grounding of the Velostat™ pads be verified.

2.0 Resistance and Resistivity Tests

The first series of tests that the Electrostatics and Surface Physics Laboratory (ESPL) performs to evaluate the electrostatic properties of a material is surface resistance. Surface resistance measurements are the main test method used in industry to characterize the ESD properties of materials, since it is believed that charge deposited onto the surface of a material will "leave" (or decay) easier from a material with lower surface resistance than from a material with high surface resistance. Surface resistance is the ratio of the DC voltage to the current flowing between two electrodes of specified configuration that contact the same side of the material and is expressed in ohms (Ω). The surface resistance tests are performed per the requirements of the ESD Association Standard Test Method ESD STM11.11 [1]. These measurements are taken using a PRS-801 resistance system with an Electro Tech System (ETS) PRF-911 concentric ring resistance probe (Cal # M81019). The tests require a five pound weight on top of cylindrical electrodes and were conducted at both ambient and low humidity conditions. Materials with a surface resistance less than 10^4 Ω are considered conductive. Materials between 10^4 Ω and 10^{11} Ω are statically dissipative and materials with a surface resistance above 10^{11} Ω are insulating according to ANSI/ESD standards.

Volume resistivity tests are also conducted to measure conductivity through the material as opposed to conductivity along the surface. These tests are conducted using the same PRS-801

resistance system with the Electro Tech System PRF-911 concentric ring resistance probe but are performed in accordance with ESD Association Standard Test Method ESD STM11.12 [2].

2.1 Surface and Volume Resistivity Results

The data below is from six test areas of the Velostat™ and tested per ESD STM11.11-2001 at 50 ± 5% Relative Humidity and 23 ± 3° C [1]. A second round of tests was performed at ~0% RH (low humidity).

Table 1. Surface and Volume Resistivity Result of Velostat™

	Velostat™ (55% RH)					Velostat™ (0% RH)				
	Surface Resistivity		Volume Resistivity			Surface Resistivity		Volume Resistivity		
	626	Ω	118	38771.43	Ω cm	439	Ω	224	73600	Ω cm
	589	Ω	97.7	32101.43	Ω cm	422	Ω	258	84771.43	Ω cm
	585	Ω	137	45014.29	Ω cm	434	Ω	223	73271.43	Ω cm
	463	Ω	123	40414.29	Ω cm	458	Ω	208	68342.86	Ω cm
	516	Ω	117	38442.86	Ω cm	600	Ω	312	102514.3	Ω cm
	566	Ω	119	39100	Ω cm	575	Ω	292	95942.86	Ω cm
Average	**557.50**	Ω		**38.97**	kΩ cm	**488.00**	Ω		**83.07**	kΩ cm
STD	**58.59**	Ω		**4.15**	kΩ cm	**78.34**	Ω		**13.78**	kΩ cm

(Note: kΩ is kilo ohms $10^3 \Omega$, MΩ is mega ohms 10^6 Ω, GΩ is giga ohms 10^9 Ω, and TΩ is tera ohms 10^{12} Ω)

The results indicate surface resistances at both humidities less than 1000 Ω signifying a conductive material. The volume resistivity is above 10^4 Ω but less 10^{11} Ω indicating statically dissipative behavior. Regardless of humidity, however, charge should be able to dissipate along the surface or through this material if properly grounded.

2.2 Point-to-Point Resistance Testing

Since the Velostat™ is conductive across the surface and statically dissipative through the bulk material it must be grounded at all times within the bore of the Solid Rocket Booster. Grounding is stated as being accomplished by simply overlaying one Velostat™ mat on top of another in series with the final mat mechanically attached to facility ground. Thus a good electrical connection between each mat and ground is required.

The mats consist of thick foam completely covered in a layer of Velostat™ attached using aluminum-coated tape. They are 57″ × 34″ × 1.25″ thick. Several resistance measurements were performed using standard 5 lb weights with conductive rubber pads between two points [3] of various configurations including: mat to mat, mat to ground and across several mats. In some

cases, measurements using the 5 lb weight were taken on top of the aluminum tape which differed from those directly on the Velostat™ directly. The large alligator clip used to ground the mats can be attached to either the Velostat™ or the aluminum tape. Both configurations were tested as well as the ground wire itself. Finally, measurements were also taken of the floor and plastic material used to keep the mats clean for the test for comparison.

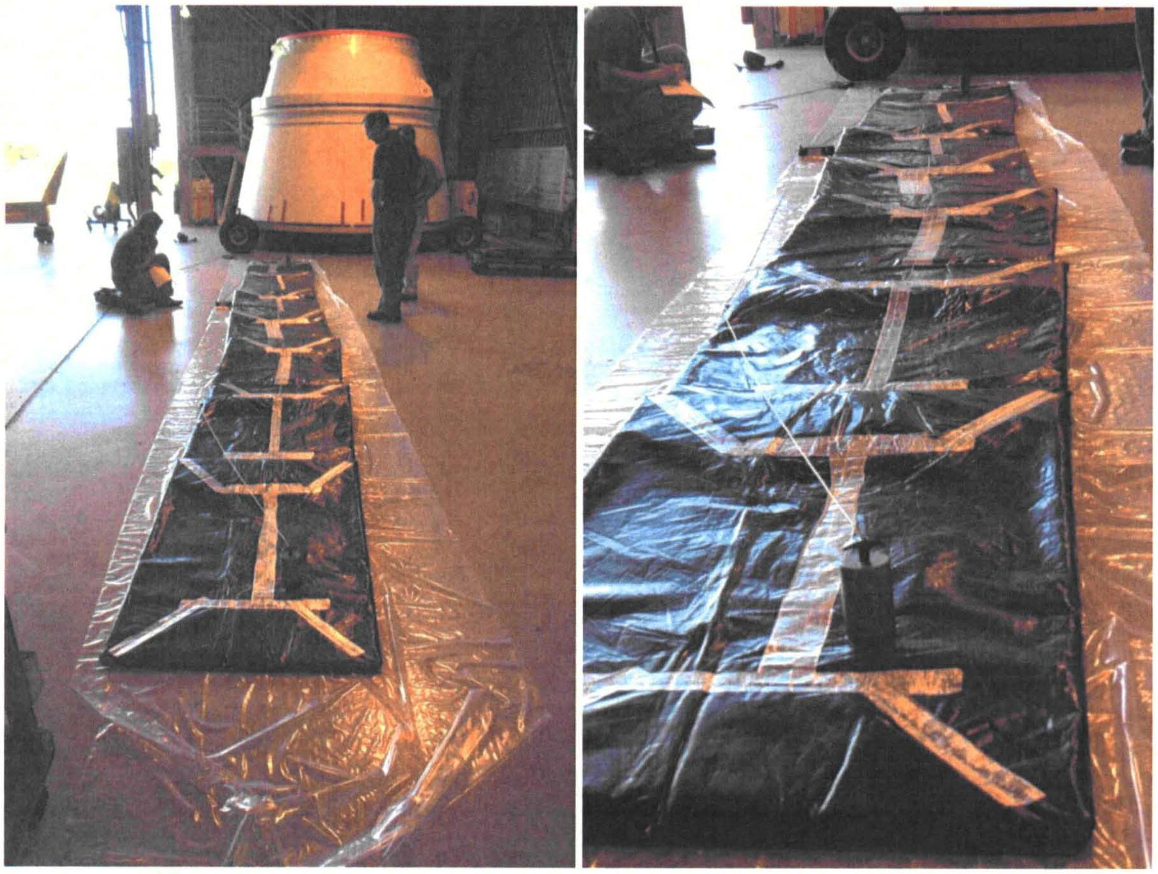

Figure 1. Seven Velostat™ mats were placed on top of plastic used for testing.

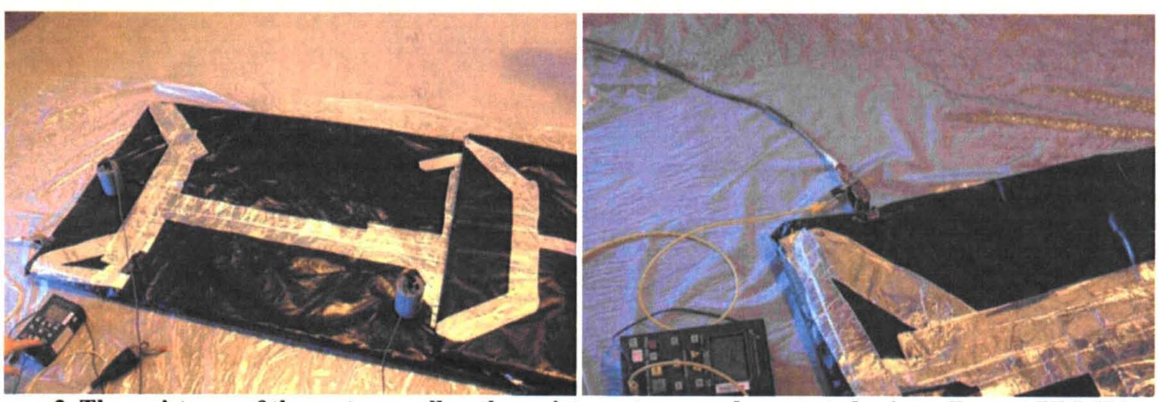

Figure 2. The resistance of the mats as well as the resistance to ground was tested using a Prostat PRS-801 Resistance Measurement System.

2.3 Resistance and Grounding Results

The results of the resistance and grounding tests are shown in Table 1 below. The humidity at the time of the measurements varied between 81.4% up to 89.9% using a Prostat Humidity Meter. The averages are in bold followed by the standard deviations below them.

Table 1. Resistance and Grounding Results

Plastic-to-Plastic	41.60	MΩ	1st Mat only	4.10	kΩ
	42.50	MΩ		3.66	kΩ
	42.40	MΩ		3.56	kΩ
	42.17	MΩ		**3.77**	kΩ
	0.49	MΩ		**0.29**	kΩ
1st-to-7th	26.10	kΩ	7th to Facility Ground	29.40	kΩ
	26.10	kΩ		27.10	kΩ
	25.70	kΩ		27.10	kΩ
	25.97	kΩ		**27.87**	kΩ
	0.23	kΩ		**1.33**	kΩ
(On Tape) 1st-to-7th	0.49	MΩ	One Mat to Another	10.10	kΩ
	0.45	MΩ		9.90	kΩ
	2.19	MΩ		9.95	kΩ
	2.83	MΩ		**9.98**	kΩ
	0.99	MΩ		**0.10**	kΩ
(On Tape) 1st-to-GND clip (tape)	3.49	MΩ	(Velostat) 1st-to-GND clip (Velostat)	3.30	kΩ
	4.18	MΩ		3.26	kΩ
	4.55	MΩ		3.21	kΩ
	4.07	MΩ		**3.26**	kΩ
	0.54	MΩ		**0.05**	kΩ
(Velostat) 1st-to-GND clip (tape)	6.50	kΩ	Ground wire itself	0.40	Ω
	5.80	kΩ		0.35	Ω
	5.46	kΩ		0.35	Ω
	5.92	kΩ		**0.37**	Ω
	0.53	kΩ		**0.03**	Ω
Floor-to-Floor	3.43	MΩ			

(Note: kΩ is kilo ohms $10^3 \Omega$, MΩ is mega ohms $10^6 \Omega$, GΩ is giga ohms $10^9 \Omega$, and TΩ is tera ohms $10^{12} \Omega$)

The results of Table 1 show that laying mats on top of each other is a successful method for establishing a sufficient ground path. The average values for each mat is about 4 kΩ while the resistance between adjacent mats is 10 kΩ. Seven mats together total only about 26 kΩ resistance. The ground clip when connected directly to the Velostat™ gives a resistance of 3.3 kΩ and when connected through the aluminum tape yields about 6 kΩ. The surface resistance across the tape is about 4 kΩ. Although the resistance increases across the tape (probably due to the adhesive), the largest resistance expected for the Velostat™ is about 28 kΩ between the last mat and facility ground. The entire assembly rested on plastic that was statically dissipative at ~ 85% relative

humidity but more resistive than the floor. Overall, all values measured are well within the recommended resistance range of $10^9\Omega$ required for safe flooring according to ANSI/ESD S 7.1 [3].

2.4 Mat removal

Figure 3 below shows the method by which operators lift and remove the Velostat™ mats. Mats are pealed from the back position forward and carried away. The initial purpose of the E3 panel discussion was to see if it were permissible to discontinue electric field scanning of the open grain at this stage of the operation. The baseline RSRM (4-segment) Propellant [composition composed of PBAN - Polybutadiene Acrylonitrile = Aluminum: 16%, HB Polymer: 12.04%, Epoxy Curing Agent (ECA): 1.96%, Ammonium Perchlorate (AP): 69.7% (30% ground (20 micron), 70% unground), Iron = 0.3%] is statically dissipative with a surface resistivity of $5 \times 10^{10}\ \Omega/\square$ (ASTM D-257 nomenclature = ANSI/ESD $5 \times 10^9\ \Omega$). Since the open grain as well as the Velostat™ mats are both statically dissipative it is unnecessary to measure static electric field generated by the separation of these two materials as they both should be well grounded with ample time to allow charge dissipation to ground. The action of separating two well-grounded materials does not cause sparking of any sort.

Figure 3. Mat removal at the end of operations.

Once the blankets are lifted the bond to ground is broken thus electrostatic charging of the mats could be a concern. Any charge generated by the personnel carrying the blanket would transfer said charge to the conductive mat which could store charge and build up its potential. The stored charge could then be released in the form of a spark to either another mat or to the open grain itself. Although workers wear Velostat™ boots, their clothing cannot be assumed to be statically dissipative. Thus this possibility must be considered.

3.0 Discussion and Conclusions

To consider the mats as a possible ignition source of the PBAN requires an estimate of the capacitance and voltage necessary for ignition. The largest capacitance of the system can be assumed to occur just as the mats are lift off of the surface. Lying flat, the largest area of the blanket is 12.5×10^3 cm^2. The closest the mat can get to the grain without touching another well grounded mat is given by the thickness of the blanket of 1.25" or 3.175 cm. Assuming parallel plate geometry the capacitance is given by $C = \varepsilon_0 A / d = 3.48 \times 10^{-10}$ F or 348 pF. Knowing the Minimum Ignition Energy for the PBAN which is 8 Joules one can calculate the voltage required for ignition through

$$E = \frac{1}{2} C V^2 .$$

Thus the voltage necessary for this case is approximately 214,423 volts. The amount of charge necessary can also be estimated through the energy of the spark since

$$E = \frac{Q^2}{2C} \Rightarrow Q = \sqrt{2EC} .$$

This corresponds to about 75 μC. For comparison, the Human Body Model [4] which is used for modeling the susceptibility of ESD damage caused by a spark from a charged person, estimates the voltage levels of the person to be between 2 kV and 15 kV, with charge levels between 0.3 μC and 2.25 μC resulting in sparks with energies between 0.3 mJ and 17 mJ. Therefore, although sparking cannot be ruled out completely, the maximum voltage and charge levels acquired on the mats as a result of human handling is never likely to reach the 214 kV or 75 μC levels required for ignition of the PBAN open grain. Furthermore, it's very likely that the use of Velostat™ boots combined with the very high humidities provides conditions which will not allow static charge to build up on personnel that can transfer to the mats.

The results above show that the method of laying mats on top of each other within the bore of the SRB is successful for charge dissipation provided the initial mat is properly grounded. Further analysis has shown that it is very unlikely that once the bond to ground is broken that the action of a charged person can generate enough charge and voltage necessary to cause an ignition of the PBAN open grain propellant.

4.0 References

1. ESDA, *Surface Resistance Measurement of Static Dissipative Planar Materials*, in *ESD STM11.11*. 2001.
2. ESDA, *Volume Resistivity Measurements of Static Dissipative Planar Materials*, in *ESD STM11.12*. 2001.
3. ESDA, *Resistance Characterization of Materials - Floor Materials*. ESD Association Standard S 7.1, 2000.
4. ESDA, *Electrostatic Discharge Association Standard for the Development of an Electrostatic Discharge Control Program for the Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)*. ANSI/ ESD S20.20, 1999.

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